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Illusory Rotations in the Haptic Perception of Moving Spheres and Planes

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Abstract. Recently, we have shown that a translating bar on which blindfolded participants position their hand is perceived as also rotating. Here, we investigated whether such an illusory rotation would also be found if a sphere or a plane (i.e. a stimulus without a clear orientation) was used as translating stimulus. We indeed found similar rotation biases: on average a stimulus that translates over a distance of 60 cm has to rotate 25° to be perceived as non-rotating. An additional research question was whether the biases were caused by the same underlying biasing egocentric reference frame. To our surprise, the correlations between the sizes of the biases of the individual participants in the various conditions were not high and mostly not even significant. This was possibly due to day-to-day variations, but clearly, more research is needed to answer this second research question.

Keywords: Spatial perception, rotation bias, parallel, psychophysics

1 Introduction

Recently, we reported that when blindfolded participants touch a bar translating to the right, this bar is perceived as also rotating counterclockwise [1]. If this same bar translates from the right of the participant to directly in front of the participant, a clockwise rotation is perceived (see Figure 1 for a picture of the set-up). This illusory rotation was predicted from results of a parallelity experiment: if participants have to make a test bar located to their right parallel to a reference bar located to their left, the test bar is always rotated clockwise with respect to the reference bar, e.g. [2–6] (see also Figure 1). Kappers showed that this rotation gradually and systematically increased with distance [7]. Therefore, the logical consequence of this mismatched parallelity was that a translating bar had to rotate in order to be perceived as non-rotating.

The explanation for these results is that although participants are instructed to make their judgements in a reference frame connected to the outside world (i.e. an allocentric reference frame), they are biased by their own egocentric reference frame (i.e. a hand-centred and/or body-centred reference frame [8]). When their hand moves from a location to their left to a location to their right, this involves also a clockwise rotation. If what is "parallel" were judged with respect to this egocentric hand reference frame, a test bar on the right has to be rotated clockwise in order to be perceived as parallel and a rightward translating bar has to rotate clockwise in order to be perceived as non-rotating. The deviations and biases found are indeed in a direction consistent with this egocentric reference frame, but they are less extreme. Thus, the deviations can be understood as originating from a biasing influence of an egocentric reference frame [8]. Interestingly, the biases are strongly participant-dependent [5], suggesting that the strength with which participants rely on their egocentric reference frame varies.

The current research addressed two questions. The first question was whether the illusory rotation depended on the presence of an object with a clear orientation. Would a participant also perceive a translating plane or sphere as rotating? In the previous study with the rotating bar, some participants tried to align their hand with the bar but because of the rotation, this was not always possible. This may have induced a greater awareness of the actual rotation resulting in smaller rotation biases. On the other hand, the changing position and orientation of the bar in combination with their moving hand that also changed in orientation, might have caused confusion resulting in larger biases. In that study, the use of a bar was motivated by the use of bars in the parallelity studies, but of course, for an illusory rotation study, a bar is not essential. In order to make the results more general, in the current study we investigated the existence of an illusory rotation in conditions where no orientation cue is present.

The second question addressed the generality of the egocentric reference frame in similar haptic tasks. We know that in different tasks different egocentric reference frames play a role [13]. In a previous study on the haptic and visual matching of the orientation of bars, it was found that whereas both haptic and visual deviations were significant, systematic and participant-dependent, the correlation between the visual and haptic deviations was only small [9]. The explained variance due to a common factor (i.e. the use of the same egocentric reference frame) was only 20 %. It was therefore of interest to investigate whether the correlations between deviations in several haptic tasks would be higher.

To answer the two research questions, we set up an experiment consisting of four conditions. In the first condition, a baseline condition termed “parallel”, we measured the deviation in a parallelity task as in many of the previous experiments, e.g. [5]. The second condition was identical to the earlier illusory rotation study and was termed “bar” condition [1]. The third and fourth conditions were new and consisted of a translating and rotating sphere and plane and these were termed “sphere” and “plane” conditions, respectively.

2 Methods

2.1 Participants

Twelve participants (8 females and 4 males) took part in the experiment. All of them were right-handed as assessed by means of a questionnaire [10]. Nine of them received a monetary compensation for their efforts; the others were colleagues from another group. None of the participants were familiar with the research questions or the set-ups. Their ages ranged from 20 to 28 years. One of the original participants was replaced because at least in one condition it became clear that she was not performing the requested task. All participants signed for informed consent. The experiments were approved by the Ethical Committee of the Human Movement Sciences Faculty.

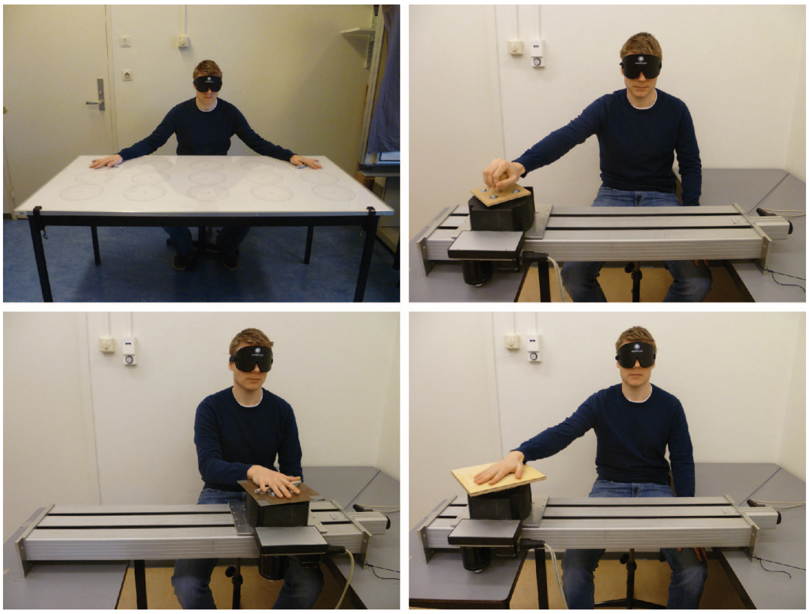

Fig. 1. Participant in the various experimental conditions. Top left: “parallel”; bottom left: “bar”; top right: “sphere”; bottom right: “plane”. In “bar” the position of the stimulus is in its leftmost position, and in “sphere” and “plane” in the rightmost position.

2.2 Set-ups

The set-up for the parallellity task was used in many earlier studies and consisted of a table on which two aluminium bars were placed (see [5] for more details and Figure 1 for a picture of the set-up). For the “sphere”, “plane” and “bar” conditions the same rotation set-up as in [1] was used. The stimulus (either a wooden sphere, wooden board or aluminium bar) was fixed onto an Isel Automation linear and rotary positioning unit, which was attached to an Isel C142-1 CNC controller. The stimulus could translate back and forth over a distance of 60 cm with a velocity of 15 cm/s while also rotating in either clockwise or counterclockwise direction (for details see [1]). The movement range of the stimulus was from directly in front of the participant to 60 cm to the right of the participant. Illustrations of a participant in the set-ups of the various conditions are shown Figure 1.

2.3 Procedure

Half of the participants started with “sphere” followed by “plane”, whereas the other half did this in opposite order. The third and fourth conditions of all participants were always “parallel” and “bar”, respectively. The motivation for this choice was that the “sphere” and “plane” conditions were new and we did not want to bias our participants in these conditions in any way. Moreover, since the “bar” condition might strengthen awareness that hand orientation changes during the trials, we preferred to have this condition after the “parallel” condition.

“Parallel” condition After checking whether the participant correctly understood the meaning of the word “parallel”, the participant blindfolded her- or himself. Next, the experimenter placed the reference bar in a fixed orientation (20, 40, 60, 80, 100, 120, 140 or 160°) and the test bar in a random orientation. One of the bars (either the reference or the test) was placed 60 cm to the right of the participant and touched by the right hand, and the other 60 cm to the left and touched by the left hand (see Figure 1). All reference orientations were presented once on the left and once on the right; left and right trials were interchanged with the reference orientations in random order. The task of the participants was to rotate the test bar so that it felt parallel to the reference bar. It took participants just a few seconds to perform one trial. The deviation, defined as the orientation of the left bar minus that of the right bar, was averaged over the 16 trials. We have chosen for this particular version of the “parallel” condition, because it has been the baseline throughout many previous studies.

“Sphere”, “plane” and “bar” conditions To explain the task and make the participants familiar with the rotation set-up and the noise it produced, two trials of the first condition (either “sphere” or “plane”) were shown to the participant. At this stage, the participant was not yet blindfolded and not allowed to touch the stimulus. Subsequently, the participant seated her- or himself on a stool, blindfolded her- or himself and the experiment started without any further instructions.

In the “sphere” condition, the participant was asked to grasp the sphere from above. In the “plane” condition, they had to place their hand centred on the board. If they misplaced their hand (because they could not see the centre), the experimenter gave verbal instructions to replace the hand. In the “bar” condition, they placed their flat hand on the bar without touching the plate on which this bar was fixed. They were explicitly told that as the rotation would sometimes be substantial, it would not always be possible to keep their hand aligned with the bar. The task was to decide on each trial (i.e. a translation to the right or a translation to the left) whether the translating stimulus (sphere, plane or bar) rotated clockwise or counterclockwise. All participants used their right hand. The start orientation of the stimulus (only relevant for the bar) was random.

Within a condition, four interleaved one-up-one-down staircases of 15 trials each were run to determine the rotation bias of a participant (see left panels of Figure 2. Two of these staircases belonged to the rightward translation, and the other two to the leftward translation. Based on previous research [1], the staircases started at -45 and 15° for the rightward trials and at -15 and 45° for the leftward trials, with step sizes of 5°. Positive rotations are counterclockwise. A rotation of 0° (i.e. no rotation) was avoided as lack of vibrations due to rotation might trigger awareness of a “special” kind of trial. As all rotation biases were far from zero, this did not cause any problems.

From the staircase data, the percentages “counterclockwise” were determined for each rotation and each participant for both the rightward and the leftward translations (see right panels of Figure 2). Psychometric curves were fitted to these data, using the

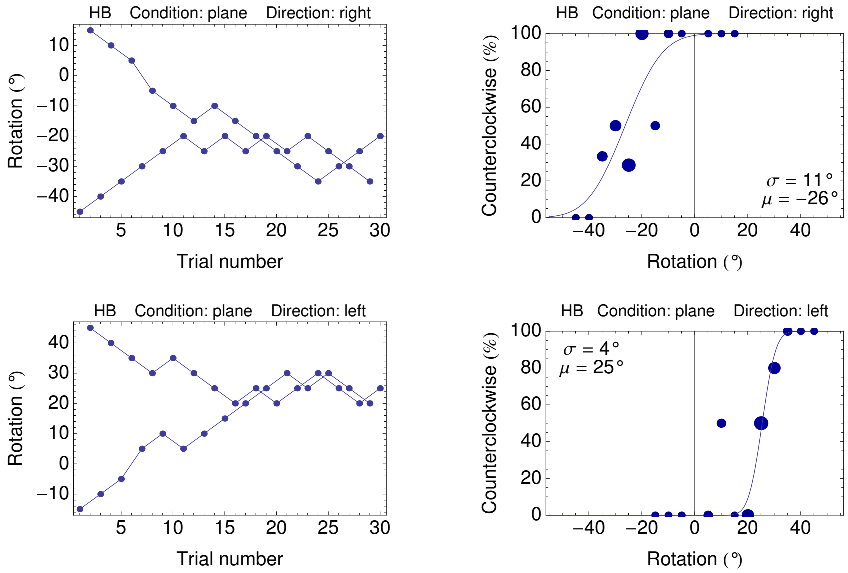

Fig. 2. Examples of the staircases and the derived psychometric curves for one participant in the "plane" condition. Upper (lower) plots are for translation to the right (left). It can be seen that for each direction, two staircases, starting from opposite rotations, converge to the rotation that is necessary to perceive the stimulus as non-rotating. The size of the plot points in the right plots gives an indication of the number of times a certain value has been presented during the staircase procedure.

following cumulative Gaussion function:

$$f(x) = 50 + 50 \text{ erf}\left(\frac{x-\mu}{\sqrt{2}\sigma}\right), \tag{1}$$

where μ is the bias (i.e. the rotation needed to perceive the stimulus as non-rotating) and σ a measure of the steepness of the curve (more precisely, the difference between the values of 50 and 84 %). The overall rotation bias is defined as:

$$\frac{1}{2}(\mu_{\text{left}} - \mu_{\text{right}}), \tag{2}$$

where the subscripts indicate the translation directions.

3 Results

The deviation and rotation biases are shown in Figure 3 for all participants and all four conditions. As the distance between the bars in the "parallel" condition was 120 cm, whereas the translation distance in the other conditions was only 60 cm, for proper comparison we divided this deviation by 2 in the graph and the analyses. In all four

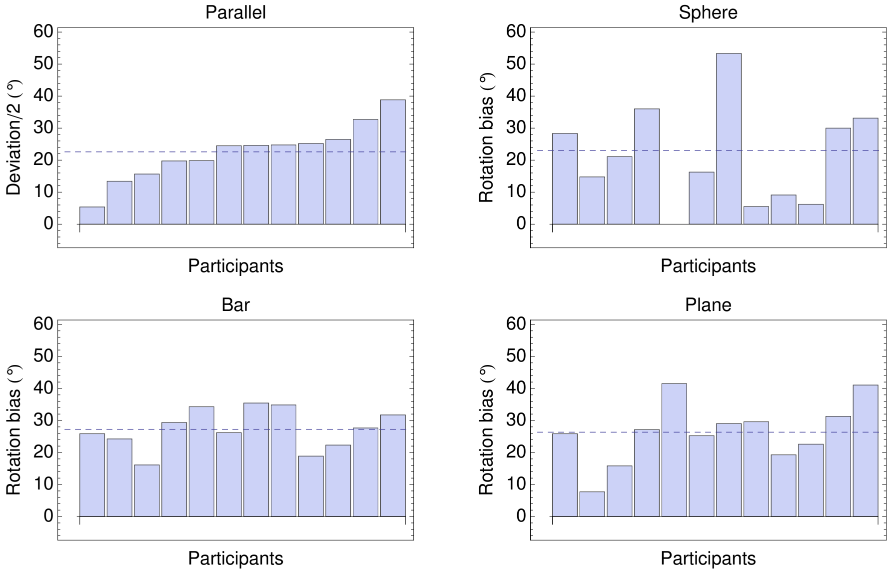

Fig. 3. Deviations found in the various conditions for the 12 participants, ordered by the deviation obtained in the "parallel" condition. Top left: "parallel"; bottom left: "bar"; top right: "sphere"; bottom right: "plane". The missing value in the "sphere" graph is due to one participant who did not show convergence in that condition. The dashed lines indicate the average over all participants within a condition.

graphs, the participants are ordered according to the size of their deviation in the "parallel" condition. The average deviation in the "parallel" condition was 45° (not yet divided by 2) with an average standard deviation of 14°. The average rotation biases in the "sphere", "plane" and "bar" conditions were 23, 26 and 27°, respectively. These values were highly significantly different from 0 (all ps < 0.0005) as determined with one-sided t-tests. In all cases, the difference between μ_{left} and μ_{right} was significantly larger than the corresponding σ averaged over the two curves (all ps < 0.005), which is another indication of the significance of the biases.

The deviations and the rotation biases in the various conditions were of about the same size (see Figure 3), which was confirmed by paired two-sided t-tests; none of these gave a significant result. The correlations between the deviation/rotation biases obtained in the various conditions are the following: "parallel" - "sphere": R = 0.07, "parallel" - "plane": R = 0.5, "parallel" - "bar": R = 0.3, "sphere" - "plane": R = 0.4, "sphere" - "bar": R = 0.5, "plane" - "bar": R = 0.7. Only the "plane" - "bar" correlation was significant ($p = 0.008$). The variances explained by these correlations were 0.6, 26, 8, 19, 23, and 52 %, respectively.

4 Discussion and Conclusions

Our first research question was whether the illusory rotation found when a translating bar was touched, would also be found in the case of translating objects without a clear orientation such as a sphere or a plane. The answer to this question was a distinct “yes”: also using a sphere or a plane as the translating stimulus strong rotation biases were found. The magnitude of these several rotation biases was about equal. Thus, this showed that the illusory rotation is more general and does not depend on the presence of an object with a clearly defined orientation. The existence of these biases shows once again that human haptic perception of the world surrounding them is not veridical.

Our second research question addressed whether the biasing egocentric reference frames in the various conditions would be correlated. Somewhat to our surprise, this turned out to be hardly the case. The variances that could be explained by the use of a common egocentric reference frame ranged from 0.6 to 52 %. Although the 52 % explained variance between the “plane” and “bar” conditions is quite substantial and significant, the other values were much smaller and not significant. In a previous study [9] the correlations between visual and haptic judgements of parallel were also relatively small (explained variance 20 %). Although the bimanual “parallel” condition was somewhat different from the other three unimanual conditions with a translation over 60 cm, it has been shown that unimanual and bimanual deviations are very similar and that the deviations vary more or less linearly with distance [4]. Therefore, we do not expect that lack of correlation was caused by this particular choice of baseline condition.

The question now is why these correlations are so small. One possibility is that the model of the biasing influence of an egocentric reference frame is incorrect and that therefore there is no reason to expect high correlations. We think it unlikely that the model would be incorrect, as its validity has been shown in many earlier studies, e.g. [8]. However, it could be the case that participants use a different egocentric reference frame for every task. Tasks in daily life differ widely and many different egocentric reference frames are known, such as retinotopic, head-centred and body-centred reference frames, e.g. [11–13]. However, these different reference frames are used in tasks that are inherently different, whereas the tasks in the current experiment, especially those in the conditions “sphere”, “bar” and “plane”, are quite similar. Still, the stimuli are touched/grasped differently in the various conditions, so such an explanation of using different egocentric reference frames cannot be excluded. A final consideration is that although the overall biases obtained in these conditions are indeed of about the same size, there were quite some interindividual differences. If this spread in the data is caused by day-to-day variations in the biases of the individual participants, then a lack of correlation can be understood. Therefore, it seems important to focus a future study on this possible day-to-day variation of the rotation biases and not just on the existence thereof. With more data from the same participants and a larger number of participants it will be possible to really answer the question whether biases in the various condition do or do not correlate.

To summarize, we can say that the existence of illusory rotation biases does not depend on the presence of an object with a distinct orientation: planes and spheres without such a clear orientation lead to similar biases. Whether these biases are caused by the same underlying biasing egocentric reference frame still remains to seen.

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